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Optimizing nitrogen utilization by integrating crop and animal production

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Abstract

The farm model was built according to the data from 9 Finnish organic farms. 20 % of area produced cash crop and 80 % was used as fodder in milk production on the farm. The model indicates that there is high potential (up to 30% compared to Finnish average) to reduce nitrogen losses in agriculture. The key factors are integration between crop and animal production, limited nutrient intensity according to the system itself and BNF. The crop rotation used in model can support milk production with relative high intensity. In this model no external fodder is used, however, it may be necessary to have a small amount of high quality processed protein concentrate, if the annual milk yield exceeds 8000 kg/cow. Crop yield by means of nitrogen yield was about 10 % lower compared to Finnish average.

Introduction

There are always limited resources available for food production, thus resource efficiency is always the key issue. Modern agriculture is using resources like external nutrients (fertilizers) and non-renewable energy in large scale. The high production intensity results in high production per hectare; however, it often results in serious environmental damages.

Organic farming has a greater emphasis on internal and renewable resources than conventional farming. Very often it also results in lower production intensity and lower production per hectare. A common criticism against organic agriculture is that it has an inefficient use of land and an inefficient use of nutrients and energy per output unit.

In this survey the whole production system is introduced and all the main nutrient flows are presented. The main focus is on nitrogen efficiency.

Based on the data from the Finnish organic farms, a farm model was constructed to illustrate the characteristics and fundamentals of integrated crop and animal production. The main focus is on nutrient flows, especially the nitrogen flow.

The two main ideas behind the organic farm model are:

1) the ratio between crop and animal production equals the Finnish average (i.e. 20 % of area for direct human consumption as crop products and 80 % for livestock fodder);

2) running the production system with the intensity based on the local renewable resources and the system itself, i.e. biological N-fixation (BNF), crop rotation, and nutrient recycling. (i.e. also feeding strategy on livestock production is based on almost 100% self-sufficiency)

Material and methods

The data was collected from nine organic farms in southern Finland for two consecutive years on each farm (2011 and 2012). Data was collected through face to face interviews with the farmers.

The evaluation of nutrient flows is based on the concept of primary nutrients developed by Seuri (Seuri 2002, 2008; Seuri and Kahiluoto 2005). In addition, surface balance was calculated and surface efficiency was defined as the ratio between harvested yield and nutrient inputs to the field. The standard statistics for Finnish agriculture were used for comparison to the model.

Farm model

T The main production line is milk in the farm model, the average annual milk yield is 8000 kg/cow. In addition, about 20% of total crop yield is sold, reflecting the average share of direct human consumption of crop yield in Finland (Table 1.).

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Table 1: Crop rotation, yields (dry matter and nitrogen) and biological nitrogen fixation (BNF) in the farm model

	legume	non-legume	N-legume	N-non-leg	N-harvested	BNF	
	(d.m. kg/ha)	(d.m. kg/ha)	(%)	(%)	(N kg/ha)	(N kg/ha)	
red clover+timothy	2000	2000	3.5	1.5	100	100	
red clover+timothy	1600	2000	3.5	1.5	86	80	
barley/wheat		2200		2	44	20	
pea+oats	1000	1100	4	2	62	50	
barley+grass seed		2300		2	46	20	

The primary source of nitrogen in the system is biological N-fixation by legumes and the amount of N-fixation determines the maximum yield potential of non-legumes. The value of 5.0 kg BNF/100 kg harvested legume biomass has been used in the model calculations. However, some BNF is not related to harvested yield, i.e. the under sown ley and yield of ley regrowth. Both were estimated to be 20 kg/ha BNF. The average total BNF was 54 kg/ha in the 5-year crop rotation. In addition to BNF, 5 kg/ha N has been added to total external input as atmospheric deposition, i.e. primary nitrogen totals 59 kg/ha.

All the other harvested crops are used as a fodder on the farm except for the cash crop yield. The amount of nitrogen in manure has been estimated to be 50% of total nitrogen content in fodder. Thus, from a total harvested N-yield (68 kg/ha) about 9 kg/ha is sold in the form of cash crop and about 30 kg/ha is left on the farm as farmyard manure (FYM). This amount of manure can be spread for one crop in a 5-year crop rotation, i.e. under sown cereal receives FYM (147 kg/ha total N). Evaluation of nutrient efficiency and comparison between the model and Finnish agriculture is presented in Table 2.

Results and conclusions

Table 2: Evaluation of nitrogen flows in the farm model and comparison with Finnish agriculture

	Model		Average for Finnish agriculture
Primary nitrogen, p	59	N kg/ha	95
Secondary nitrogen, s	30	N kg/ha	35
Total N input to the field = p+s	89	N kg/ha	130
Circulation factor, c = (p+s)/p	1.5		1.37
N-yield, y	68	N kg/ha	75
N surface balance=(p+s)-y	21	N kg/ha	55
N surface efficiency, S = y/(p+s)	0.76		0.58
Primary efficiency, P = y/p = c x S	1.15		0.79

*80 kg/ha N-fertilizers, 5 kg/ha atmospheric deposition, 5 kg/ha BNF, 5 kg/ha imported fodder

The model results in about 30% more efficient nitrogen utilization compared with the Finnish average, i.e. primary nutrient efficiency in the model is 115% versus 79% in Finnish agriculture.

According to the law of diminishing returns, the utilization efficiency decreases when the use of the input increases (production intensity increases). The average nitrogen intensity in Finnish crop production is 130 kg/ha whereas in the model it is 89 kg/ha. However, it is not likely that only a lower nitrogen intensity explains the difference in N surface efficiency (0.76 vs. 0.58). The biggest difference in nitrogen flows between the model and average Finnish agriculture is the primary source of nitrogen: in the model it is BNF, whereas in Finnish agriculture it is nitrogen fertilizers. It is obvious that utilization efficiency of BNF is very high since almost all BNF is related to harvested yield. It can be estimated that the nitrogen efficiency origin from BNF is around 85% (total BNF is 54 kg/ha, 8 kg/ha has been estimated to be related to non-harvest BNF yield). A rough estimation of nitrogen efficiency origin from FYM is 60% (the weighted average from BNF and FYM results in 76% surface efficiency when BNF efficiency is 85% and FYM efficiency is 60%). The average nitrogen utilization efficiency of FYM has been estimated to be around 20% and the efficiency of nitrogen fertilizers around 70% in Finnish agriculture.

The nitrogen yield level in the model is only 10% lower than the Finnish average. However, the difference is slightly higher (20%) if measured in terms of energy (dry matter) content of yield. The difference in cereal yields (dry matter and nitrogen basis) is around 30%, but ley yields are almost equal to the Finnish average. The proportion of leys in a crop rotation is slightly higher in the model than for the Finnish average. The main difference between the model and the Finnish average is in the protein crops: peas are hardly grown in Finland in conventional farming and rape seed is the main protein crop, but its proportion is even less than the peas in the model.

Discussion

The present agriculture (conventional and organic as well) is based on highly specialized production. It is quite doubtful to improve nutrient utilization in large scale without improving integration between the specialized production lines, i.e. integration between crop and animal production. Other key issues to improve nutrient utilization are limited nutrient intensity according to the system itself and BNF.

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